Appendix A

Emission Factor Derivations

The following physical constants and standard conditions were utilized to derive the criteria-pollutant emission factors used to calculate criteria pollutant and toxic air contaminant emissions.

standard temperature[a]:	70^{o}F
standard pressure[a]:	14.7 psia
molar volume:	385.3 dscf/ lbmol
ambient oxygen concentration:	20.95%
dry flue gas factor[b]:	8535 dscf/MM Btu
natural gas higher heating value:	1030 Btu/dscf

[a]BAAQMD standard conditions per Regulation 1, Section 228.

[b]F-factor is based upon the assumption of complete stoichiometric combustion of natural gas. In effect, it is assumed that all excess air present before combustion is emitted in the exhaust gas stream. Value shown reflects the typical composition and heat content of utility-grade natural gas in San Francisco bay area.

Table A-1 summarizes the regulated air pollutant emission factors that were used to calculate mass emission rates for each source. All units are pounds per million Btu of natural gas fired based upon the high heating value (HHV). All emission factors are after abatement by applicable control equipment.

Table A-1
Controlled Regulated Air Pollutant Emission Factors for Gas Turbines and HRSGs

Pollutant	Source			
	Gas Turbine		Gas Turbine & HRSG Combined	
	lb/MM Btu	lb/hr	lb/MM Btu	lb/hr
Nitrogen Oxides (as NO_2)	0.00718[a]	14.21	0.00718[a]	15.65
Nitrogen Oxides (as NO_2)	0.00897[b]	17.76	0.00897[b]	19.54
Carbon Monoxide	0.013[c]	25.73	0.013[c]	28.33
Precursor Organic Compounds	0.00125	2.47	0.00125	2.72
Particulate Matter (PM_{10})	0.00455	9	0.00551	12
Sulfur Dioxide	0.000693	1.37	0.000693	1.51

[a]based upon the annual average stack concentration of 2.0 ppmvd NO_x @ 15% O_2 that reflects the use of dry low-NO_x combustors at the CTG, low-NO_x burners at the HRSG, and abatement by the proposed A-1 and A-3 Selective Catalytic Reduction Systems with ammonia injection.

[b]Permit conditions will limit the stack concentration to 2.5 ppmvd NO_x @ 15% O_2 over any one hour period, while the annual NOx mass cap will based upon the annual average stack concentration of 2.0 ppmvd NO_x @ 15% O_2.

[c]based upon the permit condition emission limit of 6 ppmvd CO @ 15% O_2.

<u>REGULATED AIR POLLUTANTS</u>

NITROGEN OXIDE EMISSION FACTORS

<u>Combustion Gas Turbine and Heat Recovery Steam Generator Combined</u>

The combined NO_x emissions from the CTG and HRSG will be 2.0 ppmv, dry @ 15% O_2 on an annual average basis and 2.5 ppmv, dry @ 15% O_2 on a maximum short term (one hour) basis. These emission concentrations will also apply when the HRSG duct burners are in operation. This concentration is converted to a mass emission factor as follows:

(2.0 ppmvd)(20.95 - 0)/(20.95 - 15) = 7.042 ppmv NO_x, dry @ 0% O_2

($7.042/10^6$)(1 lbmol/385.3 dscf)(46.01 lb NO_2/lbmol)(8535 dscf/MM Btu)

= **0.00718 lb NO_2/MM Btu (annual avg.)**

(2.5 ppmvd)(20.95 - 0)/(20.95 - 15) = 8.803 ppmv NO_x, dry @ 0% O_2

($8.803/10^6$)(1 lbmol/385.3 dscf)(46.01 lb NO_2/lbmol)(8535 dscf/MM Btu)

= **0.00897 lb NO_2/MM Btu (1-hour)**

The NO_x mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

(0.00718 lb/MM Btu)(1979.4 MM Btu/hr) = **14.21 lb NO_2/hr (annual avg.)**
(0.00897 lb/MM Btu)(1979.4 MM Btu/hr) = **17.76 lb NO_2/hr (1-hour)**

The NO_x mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the gas turbine and HRSG and is calculated as follows:

(0.00718 lb/MM Btu)(2179.4 MM Btu/hr) = **15.65 lb NO_2/hr (annual avg.)**
(0.00897 lb/MM Btu)(2179.4 MM Btu/hr) = **19.54 lb NO_2/hr (1-hour)**

CARBON MONOXIDE EMISSION FACTORS

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

The combined CO emissions from the CTG and HRSG duct burner will be conditioned to a maximum controlled CO emission limit of 6 ppmv, dry @ 15% O_2 during all operating modes except gas turbine start-up and shutdown. The emission factor corresponding to this emission concentration is calculated as follows:

(6 ppmv)(20.95 - 0)/(20.95 - 15) = 21.13 ppmv, dry @ 0% O_2

($21.13/10^6$)(lbmol/385.3 dscf)(28 lb CO/lbmol)(8535 dscf/MM Btu)

= **0.013 lb CO/MM Btu**

The CO mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

(0.013 lb/MM Btu)(1979.4 MM Btu/hr) = **25.73 lb CO/hr**

The CO mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the CTG and HRSG and is calculated as follows:

(0.013 lb/MM Btu)(2179.4 MM Btu/hr) = **28.33 lb CO/hr**

PRECURSOR ORGANIC COMPOUND (POC) EMISSION FACTORS

Combustion Gas Turbine

The POC emissions from the CTG and HRSG duct burner will be conditioned to a maximum controlled emission limit of 1 ppmv, dry @ 15% O_2 during all operating modes except gas turbine start-up and shutdown. The POC emission factor corresponding to this emission concentration is calculated as follows:

(1 ppmv)(20.95 - 0)/(20.95 - 15) = 3.521 ppmv, dry @ 0% O_2

($3.521/10^6$)(lbmol/385.3 dscf)(16 lb CH_4/lbmol)(8535 dscf/MM Btu)
= **0.00125 lb POC/MM Btu**

The POC mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

(0.00125 lb/MM Btu)(1979.4 MM Btu/hr) = **2.47 lb POC/hr**

Combustion Gas Turbine and Heat Recovery Steam Generator Combined

The POC mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the CTG and HRSG and is calculated as follows:

(0.00125 lb/MM Btu)(2179.4 MM Btu/hr) = **2.72 lb POC/hr**

PARTICULATE MATTER (PM_{10}) EMISSION FACTORS

Combustion Gas Turbine

Westinghouse has predicted a PM_{10} emission rate of 9 lb/hr at maximum load for the gas turbine. The corresponding PM_{10} emission factor is therefore:

(9 lb PM_{10}/hr)/(1979.4 MM Btu/hr) = **0.00455 lb PM_{10}/MM Btu**

The following stack data will be used to calculate the grain loading at standard conditions for full load gas turbine operation without duct burner firing to determine compliance with BAAQMD Regulation 6-310.3.

PM_{10} mass emission rate:	9 lb/hr
flow rate:	978,700 acfm @ 12.33% O_2 and 170^oF
moisture content:	9.38% by volume

Converting flow rate to standard conditions:

(978,700 acfm)([70 + 460 ^oR]/[170 + 460 ^oR])(1 – 0.0938) = 746,120 dscfm

Converting to grains/dscf:

(9 lb PM_{10}/hr)(1 hr/60 min)(7000 gr/lb)/(746,120 dscfm) = 0.0014 gr/dscf

Converting to 6% O_2 basis:

(0.0014 gr/dscf)[(20.95 - 6)/(20.95 – 12.33)] = 0.0024 gr/dscf @ 6% O_2

Combustion Gas Turbine and HRSG Combined

The PM_{10} emission factor is based upon the vendor prediction of 12 lb/hr at the maximum combined firing rate of 2179.4 MM Btu/hr during duct burner firing and steam injection power augmentation. The corresponding PM_{10} emission factor is therefore:

(12 lb PM_{10}/hr)/(2179.4 MM Btu/hr) = **0.00551 lb PM_{10}/MM Btu**

It is assumed that this PM_{10} emission factor includes secondary PM_{10} formation of particulate sulfates.

The following stack data will be used to calculate the grain loading for simultaneous CTG and HRSG operation at standard conditions to determine compliance with BAAQMD Regulation 6-310.3.

PM_{10} mass emission rate:	12 lb/hr
typical flow rate:	1,071,800 acfm @ 10.54 % O_2 and 170 ^oF
typical moisture content:	14.29% by volume

Converting flow rate to standard conditions:

$(1{,}071{,}800 \text{ acfm})(70 + 460\ ^oR/170 + 460\ ^oR)(1 - 0.1054) = 806{,}637 \text{ dscfm}$

Converting to grains/dscf:

$(12 \text{ lb } PM_{10}/\text{hr})(1 \text{ hr}/60 \text{ min})(7000 \text{ gr/lb})/(806{,}637 \text{ dscfm}) = 0.0017 \text{ gr/dscf}$

Converting to 6% O_2 basis:

$(0.0017 \text{ gr/dscf})[(20.95 - 6)/(20.95 – 10.54)] = 0.0025 \text{ gr/dscf @ } 6\%\ O_2$

SULFUR DIOXIDE EMISSION FACTORS

Combustion Gas Turbine & Heat Recovery Steam Generator

The SO_2 emission factor is based upon an expected average natural gas sulfur content that will not exceed 0.25 grains per 100 scf and a higher heating value of 1030 Btu/scf as specified by PG&E. Although the maximum sulfur content can be as high as 1.0 grain per 100 scf, the actual sulfur content is likely to be much less.

The sulfur emission factor is calculated as follows:

$(0.25 \text{ gr/100scf})(10^6 \text{ Btu/MM Btu})(2 \text{ lb } SO_2/\text{lb S})/[(7000 \text{ gr/lb})(1030 \text{ Btu/ scf})(100 \text{ scf})]$

= **0.000693 lb SO_2/MM Btu**

The corresponding mass SO_2 emission rate at the maximum combined firing rate of 2179.4 MM Btu/hr is:

$(0.000693 \text{ lb } SO_2/\text{MM Btu})(2179.4 \text{ MM Btu/hr}) = 1.51 \text{ lb/hr}$

The corresponding SO_2 mass emission rate at the maximum gas turbine firing rate of 1979.4 MM Btu/hr is:

$(0.000693 \text{ lb } SO_2/\text{MM Btu})(1979.4 \text{ MM Btu/hr}) = 1.37 \text{ lb/hr}$

This is converted to an emission concentration as follows:

(0.000693 lb SO_2/MM Btu)(385.3 dscf/lb-mol)(lb-mol/64.06 lb SO_2)(10^6 Btu/8535 dscf)

= 0.49 ppmvd SO_2 @ 0% O_2

which is equivalent to:

(0.49 ppmvd)(20.95 - 15)/20.95 = 0.14 ppmv SO_2, dry @ 15% O_2

Toxic Air Contaminants

The following toxic air contaminant emission factors were used to calculate worst-case emissions rates used for air pollutant dispersion models that estimate the resulting increased health risk to the maximally exposed population. To ensure that the risk is properly assessed, the emission factors are conservative and may overestimate actual emissions.

Table A-2
TAC Emission Factors[a] for Gas Turbines and HRSG Duct Burners

Contaminant	Emission Factor (lb/MM scf)
Acetaldehyde[d]	6.86E-02
Acrolein[b]	2.37E-02
Ammonia[c]	6.63
Benzene[d]	1.36E-02
1,3-Butadiene[d]	1.27E-04
Ethylbenzene	1.79E-02
Formaldehyde[d]	1.10E-01
Hexane	2.59E-01
Naphthalene	1.66E-03
PAHs[b,d]	1.06E-04
Propylene	7.70E-01
Propylene Oxide[d]	4.78E-02
Toluene	7.10E-02
Xylene	2.61E-02

[a]California Air Toxics Emission Factors (CATEF) Database as compiled by California Air Resources Board under the Air Toxics Hotspot Program, mean values.

[b]Acrolein and PAHs rates are from Calpine source test results

[c]based upon maximum allowable ammonia slip of 5 ppmv, dry @ 15% O_2 for A-1 and A-3 SCR Systems

[d]carcinogenic compound

Table A-3
TAC Emission[a] Factors Cooling Tower

Contaminant	Emission Factor (ppm)
Ammonia	4
Arsenic	0
Cadmium	0
Chromium III	0
Copper	0
Lead	0
Mercury	0
Nickel	0
Silver	0
Zinc	0
PAHs	0

[a] The cooling tower uses recycled water from the City of Hayward's water pollution control facility. An advanced water treatment, utilizing reverse osmosis and micro filtration removes dissolved solids (TDS) and HAPs from the plant feedwater.

AMMONIA EMISSION FACTOR

Combustion Gas Turbine & Heat Recovery Steam Generator

Each Gas Turbine/HRSG power train will exhaust through a common stack and be subject to a maximum ammonia exhaust concentration limit of 5 ppmvd @ 15% O_2.

(5 ppmvd)(20.95 - 0)/(20.95 - 15) = 17.61 ppmv NH_3, dry @ 0% O_2

$(17.61/10^6)$(1 lbmol/385.3 dscf)(17 lb NO_2/lbmol)(8535 dscf/MM Btu)

= **0.0066 lb NH_3/MM Btu**

The NH_3 mass emission rate based upon the maximum firing rate of the gas turbine alone is calculated as follows:

(0.0066 lb/MM Btu)(1979.4 MM Btu/hr) = **13.06 lb NH_3/hr**

The NH_3 mass emission rate when duct burner firing occurs is based upon the maximum combined firing rate of the gas turbine and HRSG and is calculated as follows:

(0.0066 lb/MM Btu)(2179.4 MM Btu/hr) = **14.38 lb NH_3/hr**